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# LAV STRUT CAP STUDY


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METALS RESEARCH BRANCH

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MATERIALS TESTING AND EVALUATION BRANCH


September 1991



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## ABSTRACT

The problem of cracking in Light Armored Vehicle (LAV) strut caps made of high hardness armor was addressed. The current manufacturing process is reviewed, as well as the history and mode of cracking. A finite element method was employed to elucidate the stress field in the strut cap and in the surrounding ballistic hull. Finally, alternative fabrication procedures and designs are proposed and recommendations given to alleviate this problem.

## CONTENTS

## INTRODUCTION

The family of Light Armored Vehicles (LAVs) made for the U. S. Marine Corps by the Diesel Division, General Motors of Canada, Ltd. (DDGM) are fabricated from high hard steel armor, as per MIL-A-46100, above the beltline. The lower part of the vehicle employs rolled homogeneous steel armor, as per MIL-A-12560. Since deployment of the LAVs in 1983 cracking has occurred in the high hard steel plate in a number of locations. Many of these cracks started at free cut edges such as around doors and hatch covers. Details of cracking in high hard armor plate, fabrication procedures, and mechanical and ballistic properties are given in a separate report;[1] however, some cracking has occurred in the shock absorber/strut tower caps during field operations.

In an effort to find a solution to this problem, a finite element analysis of the stresses occurring in and around the strut caps was conducted. The object of this report, therefore, is to provide the details of the finite element analysis and recommend new production methods for strut caps that should eliminate cracking.

## MANUFACTURING AND CRACKING

There are four strut cap assemblies on each vehicle at the top of the two strut towers for the front two wheels on each side. The location of these caps is shown in Figure 1. Each assembly is composed of two curved pieces of high hard steel plate 6.31 mm (nominal) in thickness. They are fabricated entirely in the fully heat-treated (hardened) condition. The two components are first sectioned from a larger plate by underwater plasma-arc cutting followed by edge grinding. The cut sections are then cold formed to their final shape, as shown in Figure 2. Upon examination of the sections it appears that these are formed by sequential bending; i.e., they are clamped, bent a little, moved about 1-1/4 inches, bent some more, and so forth. The sections do not have a uniform, smooth curvature but instead exhibit ridges of high curvature with strips of relatively planar regions between them. This operation introduces a considerable residual tensile stress in the outside grains, particularly at the ridges where the plate has been bent to the smallest radius of curvature.

After severe field operations cracking has occurred in strut caps and in the surrounding welds. The cracks often run vertically up from the lower weld; i.e., parallel with the forming axis and along the aforementioned ridges, as shown in Figure 3. It is likely that these cracks initiated in the hard region of the heat-affected zone of the lower weld. An example of a field service report is given in Figure 4. In this case cracking was initiated within the high stress regions of the welds. A number of cracking problems associated with strut tower caps are summarized in Table A1 (see Appendix). This data is compiled from Integrated Logistics Support (ILS) Field Service Reports made by DDGM personnel. An examination of the field reports reveals a number of small cracks associated with strut cap welds.

The cracking problem in strut caps appears to be more prevalent in the right front cap; that is, on the engine side of the vehicle. Also, the problem appears to be more severe at Camp Pendelton and at other western Marine Corps bases than at Camp LeJeune. While it is difficult to quantify, it does seem that the additional weight on the right side of the vehicle and the rougher terrain at the western bases contribute to higher loading on these strut caps and, thus, to their more prevalent cracking.

1. WELLS, M. G. H., WEISS, R. K., and MONTGOMERY, J. S. *LAV Armor Plate Study.* U. S. Army Materials Technology Laboratory, in process.

At this point it does not appear that corrosion is playing a significant part in the cracking of strut caps.

## FINITE ELEMENT ANALYSIS

### Model and Software

A finite element analysis was conducted to determine the stress field existing in the strut cap and in the surrounding structure. Actual dynamic loads generated when normally operating the vehicle are presently not available, so an equivalent static load was applied to the strut cap in the area where it is joined to the shock tower. The strut cap and the surrounding structure, shown in Figures 5 and 6, were modelled using the Numerically Integrated Elements for System Analysis (NISA II) finite element code[2] to conduct an elastic static analysis. The results to be discussed do not determine the maximum stress values but only the stress field which exists during dynamic loading. The stress field can be used to determine if the design tends to equally distribute the stresses due to loading. If not equally distributed, the stress field will show areas where the stress is concentrated and there is a probability of material failure.

The analysis of the strut cap is a static linear elastic model with a static load approximately equivalent to a 3g dynamic load. The load was applied as a line load along the interface between the side plate and the shock tower. It is along this interface that the shock tower is first welded to the side plate. The strut cap is then set on the opening in the side plate and welded completely around its perimeter. In the model, the side plate was made sufficiently large so that the fixed boundary condition along its perimeter would have minimal effect on the local stress distribution. The actual local stress distribution that is determined for the plate and strut is the von Mises stress.

### Results and Discussion

The finite element model of the strut cap is shown in Figure 7. The results of the analysis are shown in Figure 8 where the von Mises stress values are plotted as stress contour lines. It is clear from these results that there are stress concentrations existing at the two side corners and at the lowest portion of the interface between the vertical side of the strut cap and the surrounding side plate. These are shown as points A, B, and C, respectively, in Figure 7; these are also the areas where failures have been observed in the field, cf Figure 3.

## ALTERNATIVE FABRICATION/DESIGN

From an examination of strut caps and the stress concentration points obtained by finite element analysis some alternative fabrication procedures and designs have been considered to alleviate the problem.

### Strut Cap Fabrication

(1) To facilitate forming of the two strut cap components, the parts could be made from Rolled Homogeneous Armor (RHA), as described in MIL-A-12560. This steel has a higher ductility and toughness but a lower hardness, as shown in Table 1. Because RHA has poorer

2. *Numerically Integrated Elements for System Analysis (NISA), Version 90.0.* Engineering Mechanics Research Corporation, 1607 E. Big Beaver Road, Troy, MI 48083, 1990.

ballistic performance, the thickness of the strut cap pieces would have to be increased from 6.31 mm (nominal) to 9.71 mm (nominal) to retain the same level of ballistic protection. This method of fabrication has a number of advantages. Because RHA has a lower yield strength, the residual stresses introduced during forming will be lower. Additionally, RHA is a much more forgiving material than high hard armor with respect to cutting, welding, and forming.

Table 1. MECHANICAL PROPERTIES OF HIGH HARD AND ROLLED HOMOGENEOUS ARMORS

| Armor Specification | Hardness (BHN) | Yield Strength (ksi) | Tensile Strength (ksi) | Elongation (%) | Reduction of Area (%) | Charpy Energy (ft-lb) |
|---|---|---|---|---|---|---|
| MIL-A-46100 | 477 - 534 | 195 - 210 | 240 - 270 | 12 - 9 | 48 - 34 | 14 - 10 |
| MIL-A-12560 | 321 - 388 | 165 - 180 | 180 - 220 | 16 - 14 | 59 - 57 | 30 - 16 |

(2) Make the caps by forming the two components of the strut cap from annealed (softened) MIL-A-46100 steel plate followed by rehardening and tempering. This manufacturing method would also minimize residual stresses. A possible manufacturing route is given below:

- Heat Treater: Anneal high hard plates from DDGM
- DDGM: Cut the two strut cap components and form to shape
- Heat Treater: Reheat treat (harden and temper)

An alternative procedure would be to cut the shapes from high hard steel, anneal, form, and reharden. Careful edge grinding after such cutting is mandatory. In this case, shipment to the heat treater would be easier with the much smaller components. In either case, one or two iterations may be required to develop the optimum process.

Parts made by any of these methods could also be used for field repair, as well as for future production.

**Welding**

The present strut caps are welded to the vehicle side plates using Gas Metal Arc Welding (GMAW) with a ferritic weld wire, ER70S-2. Since a number of weld-related problems have occurred with the strut caps (see Appendix), the use of austenitic stainless steel weld wire should be considered. Work on the use of stainless steel for repair welding of high hard armor was conducted at the U. S. Army Materials Technology Laboratory (MTL) in 1983. Also, it is understood that the use of this material was considered at the outset of the LAV program but was not implemented.

In Europe, austenitic stainless steel is used extensively for the welding of medium carbon high hardness armor plate steels. Susceptibility to hydrogen or delayed cracking is reduced. Austenitic weld metal has a lower yield stress than the ferritic grades normally used and is very tough and ductile. Thus, cold cracking tendency would be considerably reduced. Since

the strut caps are welded onto the vehicle side plate, which extends underneath the weld, the ballistic properties of the weld region of strut caps is not a factor around the perimeter.

**Front Suspension System**

During rough terrain and high speed maneuvers the two front wheels sometimes bottom out; in this case, the top of the tires hit the sponson. (Very occasionally, the second set of wheels toward the rear also bottom out.) In severe cases, the strut can bend near the bottom attachment point and the wheel A-frame can also bind. Concern had been expressed that when the bottoming out occurs a shock load would be applied to the top of the strut mounting and, thus, to the strut tower. However, measurements show that when the tire hits the sponson, there are several inches of travel available on the coil springs; i.e., the springs do not go solid, although a few coils at each end compress and actually touch each other in the tapered part of the spring. Thus, no impact/shock load would be applied to the top of the strut tower. It may be worthwhile to consider design modification to the front suspension system.

Therefore, while rough terrain driving does apply heavy loads through the strut tower, no impact conditions through the coil springs to the top of the tower appear to exist; however, the possibility exists that shock loads could be transmitted through the strut to the ball and socket assembly located at the top of the strut tower. As the finite element analysis shows, these stresses can cause cracking in the strut caps particularly for the right front cap on the engine side.

## SUMMARY/RECOMMENDATIONS

- Manufacture the two strut cap components from rolled homogeneous armor plate (see MIL-A-12560) to replace the presently used high hard armor steel. These caps would be used for all new production vehicles and for existing vehicle replacement when required.
- Consider new austenitic stainless steel weld metal for existing vehicle replacement; MTL is developing a procedure.
- Consider a redesign of the front suspension system.
- Corrosion on the inside of the strut caps is minimal for most service environments and does not appear to be contributing to or causing cracking.

## ACKNOWLEDGMENTS

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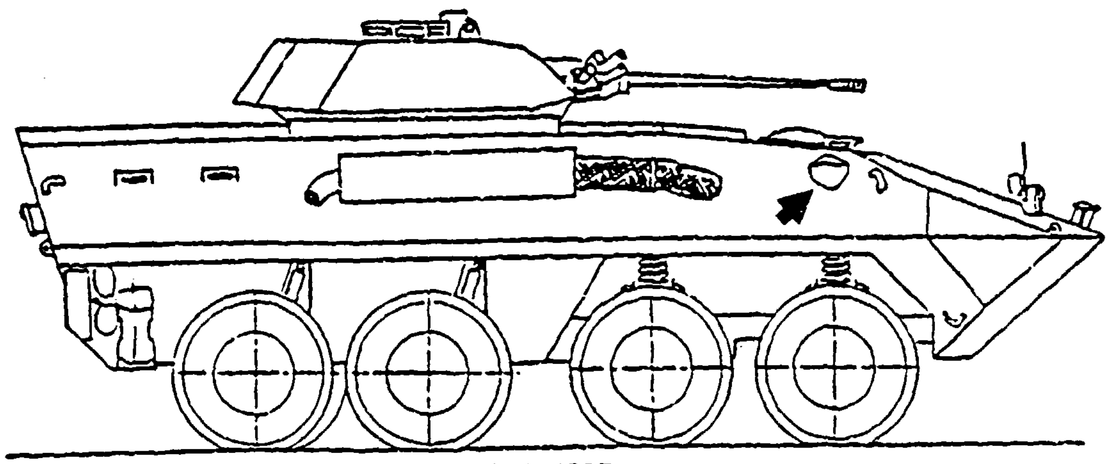
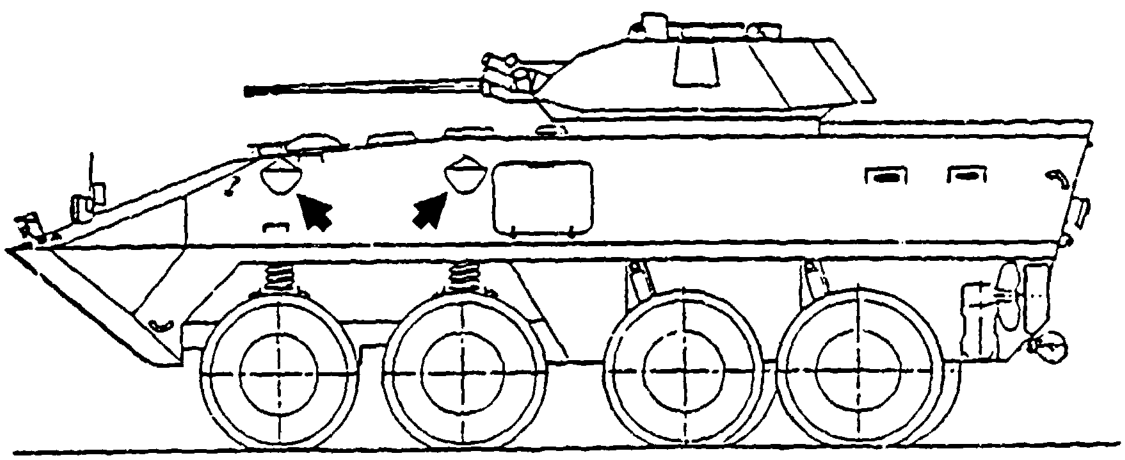
BATTLE DAMAGE/ACCIDENT CHART

LAV-25(MC)



RIGHT SIDE



LEFT SIDE

VEHICLE SERIAL NO. ____________________

SUPPLEMENTAL INFORMATION:

Figure 1. The locations of the four strut cap assemblies on the LAV are shown by the arrows.

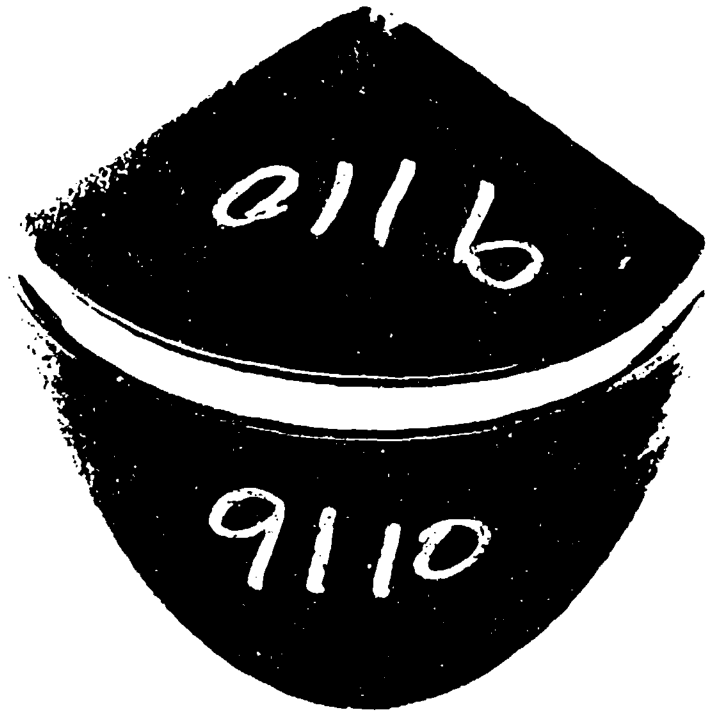
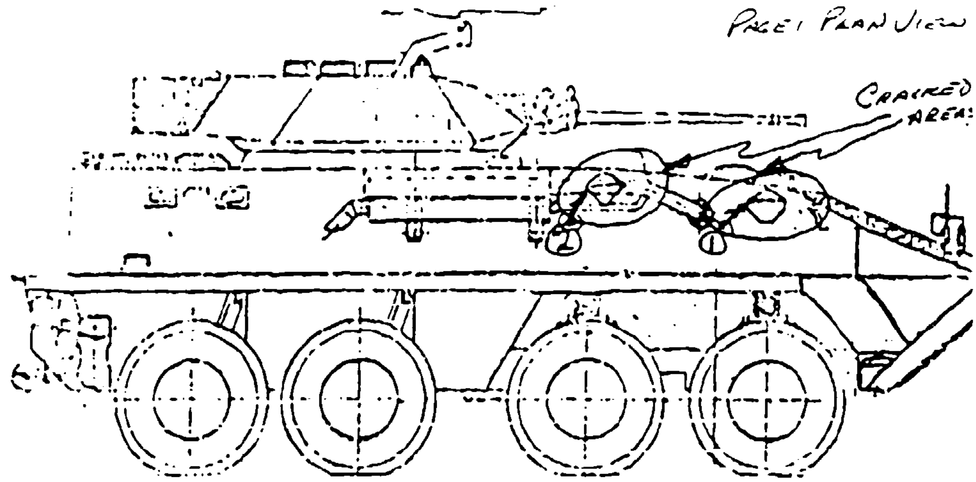



Figure 2. Photograph showing two strut cap components prior to installation. These parts are cold formed from 6.31 mm high hard armor plate.

Figure 3. Photograph of cracks in the lower strut cap piece of a fielded LAV. The cracks nucleated in the lower weld region and propagated vertically upwards.




| | | | |
|---|---|---|---|
| MODEL | MC-25 | AUTHOR | F. CLEMENT<br>R. IMBEAU |
| DDGM S/N | LAV-613-5-86 | REPORT DATE | 15 Oct 87 |
| USMC S/N | 521763 | HULL | ☑ |
| VEH MILES | 137.5 | HATCH | ☐ |
| VEH HOURS | 18.7 | DOOR | ☐ |
| VEH LOC'N | ALBANY GA. | | |
| UNIT | MPS II | | |

STORYBOARD

- CRACK LENGTH ① 3MM CRATER CRACK TYPE A ② 8MM UNDERBEAD CRACK TYPE C
- START/STOP POINT END OF WELD STRUT TO SIDESHEET-TO.
- COMMENTS VISUAL INDICATIONS FOUND WITH FLUORESC ① INDICATION REMOVED BY GRINDING. NO WELDING REQUIRED. EXCAVATION LPI ACCEPT ② INDICATION REMOVED BY GRINDING AND EXCAVATION LPI CHECKED - ACCEPT AREA WAS REWELDED AND LPI CHECK ACCEPT PAINT TOUCH UP COMPLETED

20 OCT 87

Figure 4. A typical example of a Field Service Report with weld cracks in the strut caps.

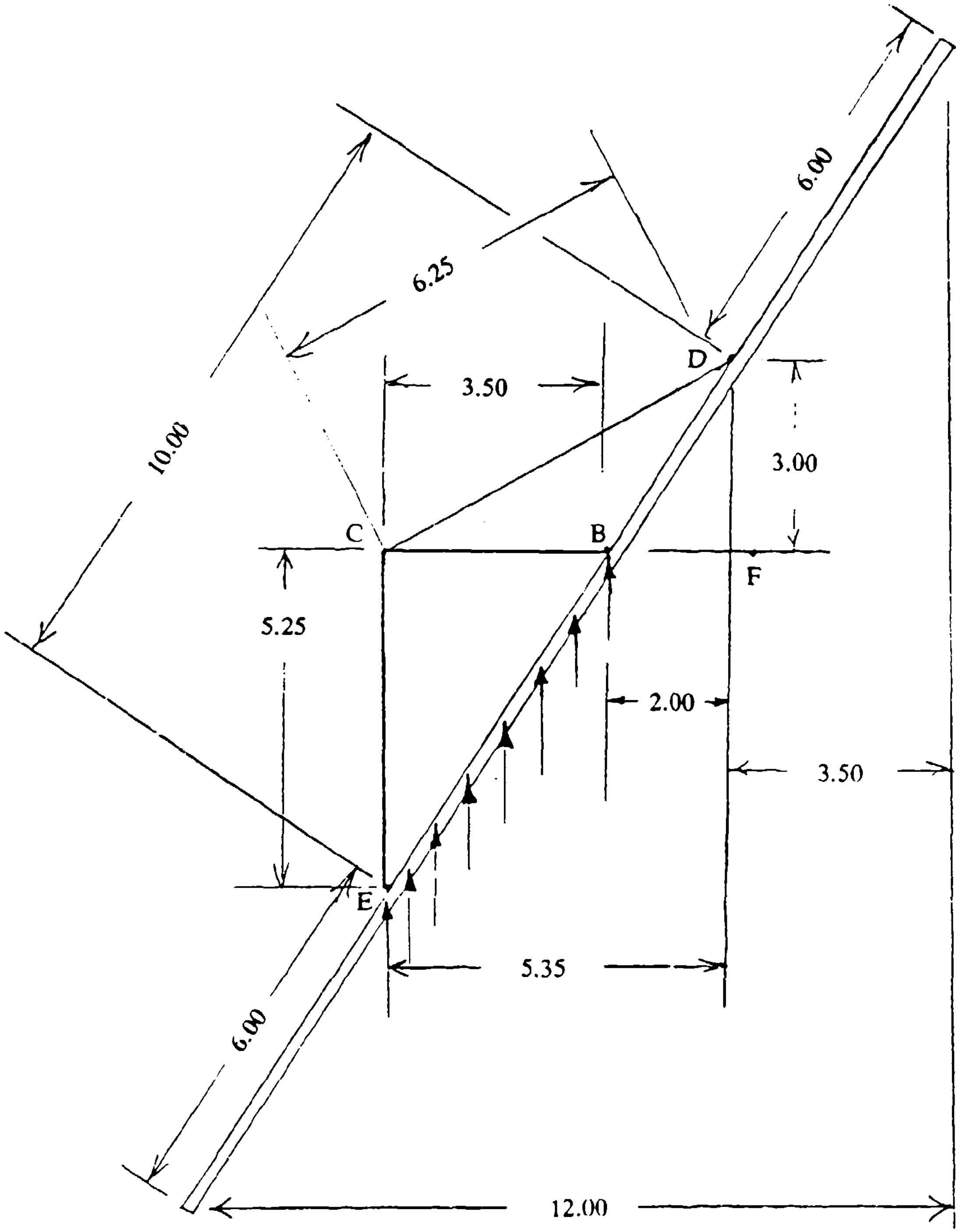



Figure 5. Side view from the front showing the dimensions of the two components of the strut cap assembly on the LAV.

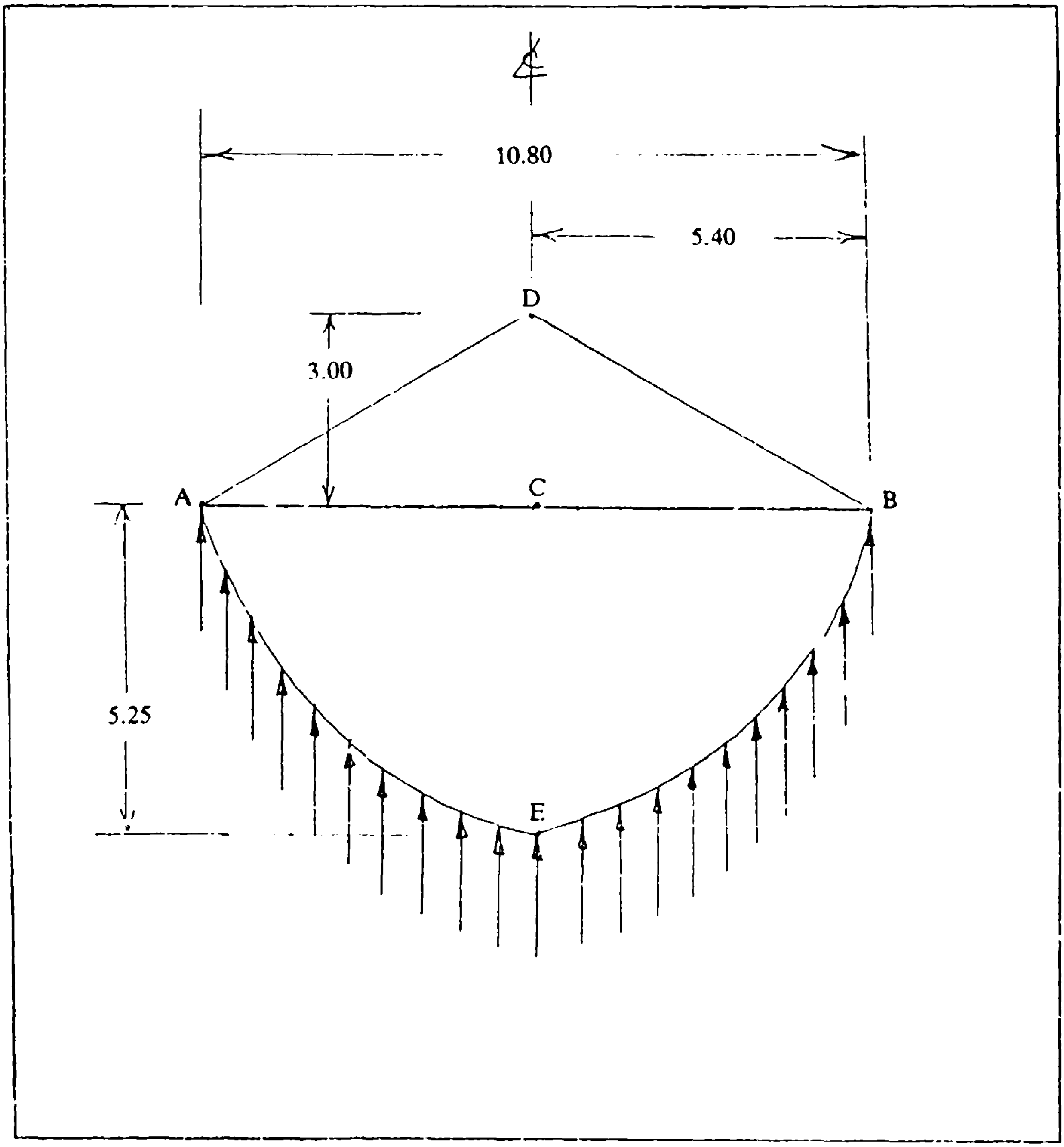



Figure 6. Side view from the side giving dimensions of the strut cap pieces on the LAV

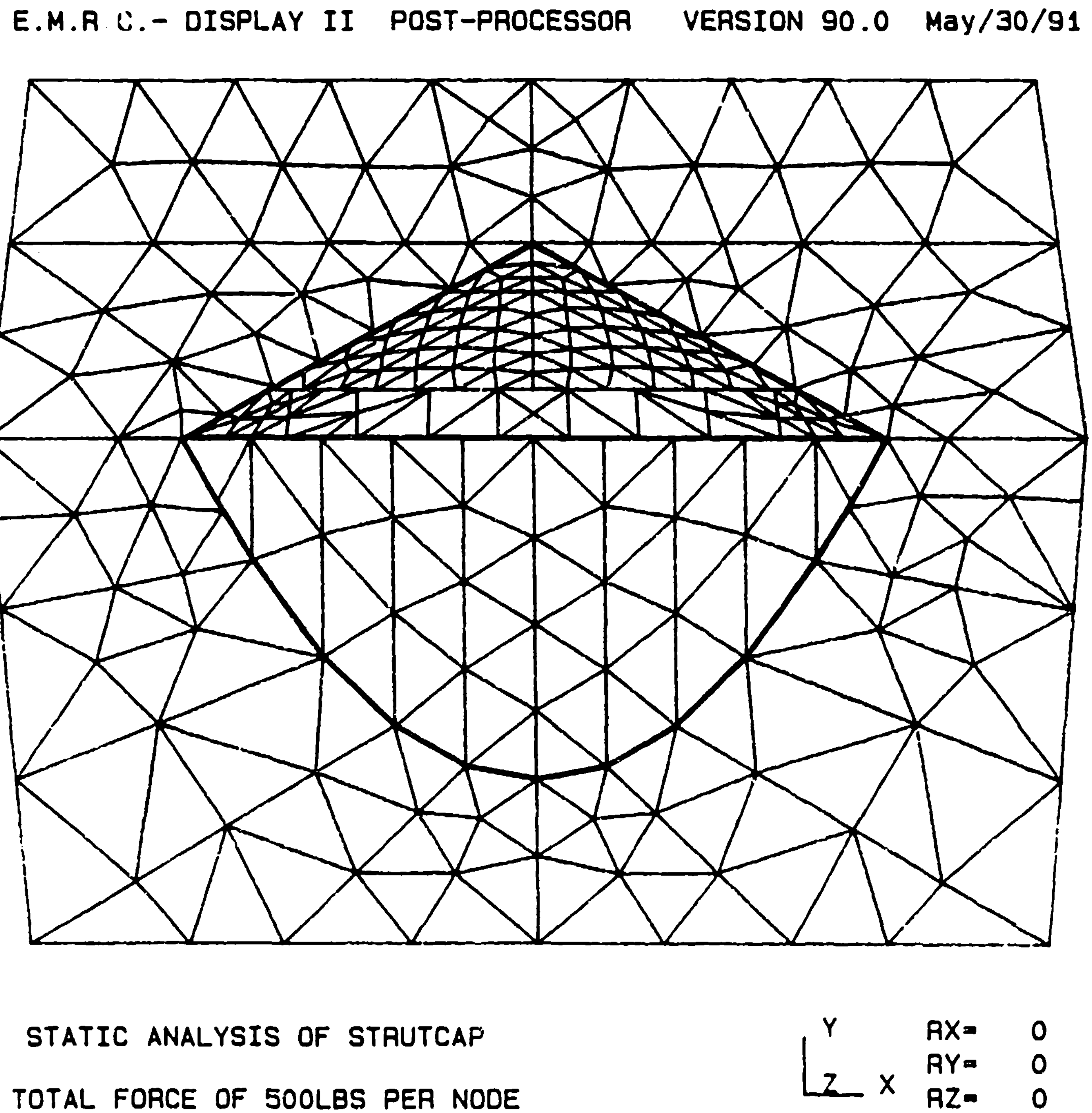



Figure 7. Finite element mesh of the welded strut cap assembly (front view).

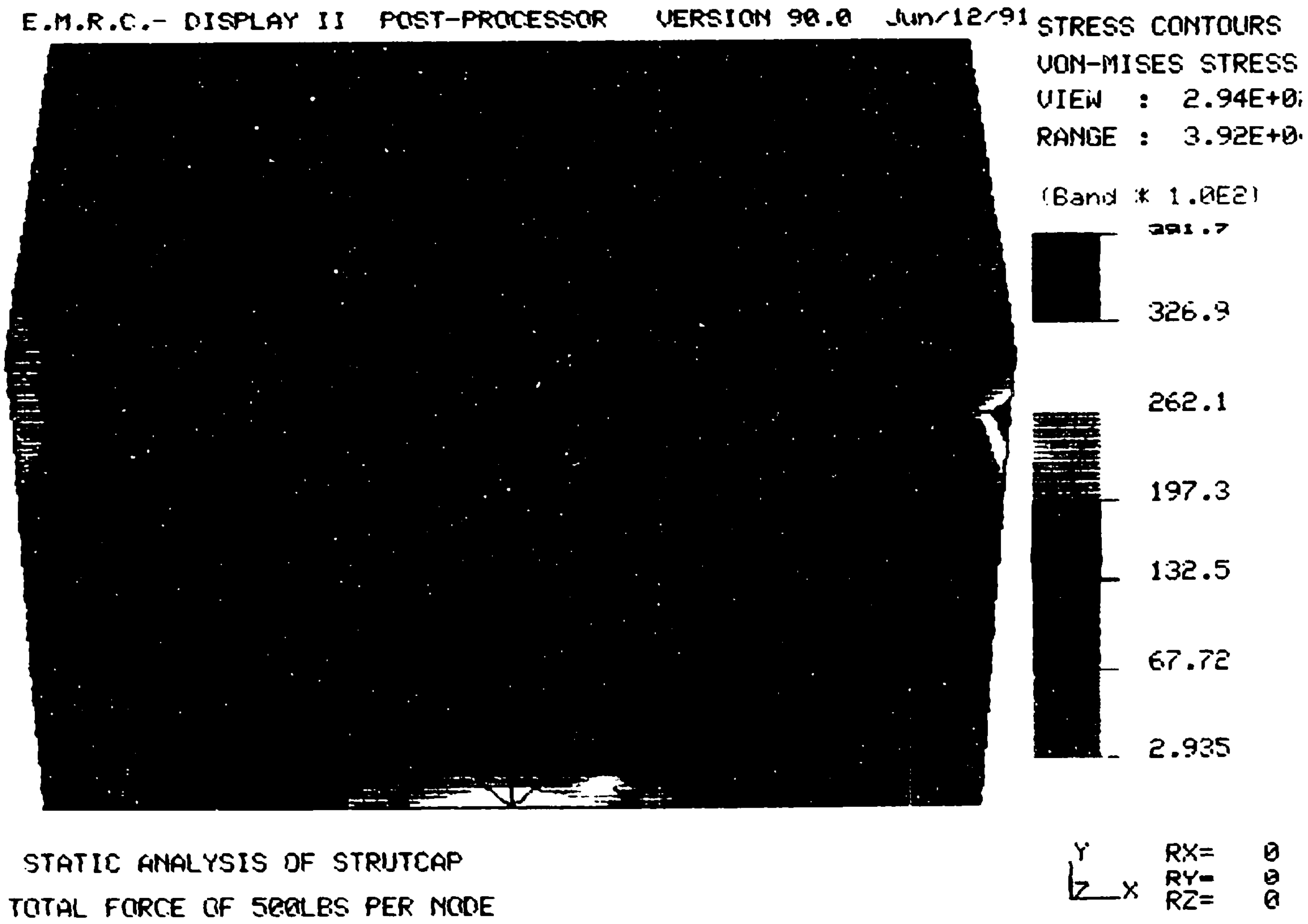



Figure 8. Von Mises stress contour (finite element analysis) on the strut cap.

## APPENDIX

Table A1. FIELD SERVICE REPORTS OF STRUT CAP CRACKING

| LAV SN | USMC SN | Report Date | Discontinuity/Visual Indication |
|---|---|---|---|
| 380 | 521681 | 08 Oct 87 | • 5 mm to 7 mm Underbead Crack at Weld, and 6 mm Straight Edge Crack in Plate at RH Front Strut Tube |
| | | | • 2 mm Crater Crack in Weld at LH Rear Strut Tube (Cracks Ground Out — OK) |
| 385 | 521684 | 08 Oct 87 | • 3 mm Crater Crack in Weld at LH Front Strut Tube |
| | | | • 3 mm Crater Crack in Weld at LH Rear Strut Tube (Cracks Ground Out — OK) |
| 386 | 521685 | | • 3 mm Crack Edge of Weld (Underbead) Strut Tube Cap LH Rear Strut Tower (Cracks Ground Out — OK) |
| 387 | 521688 | 07 Oct 87 | • 4 MM to 7 mm Long Underbead Crack at Weld on RH Rear Strut Tower (Reversed — OK) |
| 451 | 521704 | 14 Oct 87 | • 6 mm Crack on Weld Face and 3 mm Edge Crack RH Rear Strut Tower |
| | | | • 2 mm Crater Crack in Weld at LH Rear Strut Tower |
| 610 | 521762 | 15 Oct 87 | • 4 mm and 3 mm Underbead Crack on Welds at RH Rear Strut Tower |
| 613 | 521763 | 15 Oct 87 | • 3 mm Crater Crack in Weld at RH Front Strut Tower |
| | | | • 8 mm Underbead Crack at Weld on RH Rear Strut Tower |
| | | | • 6 mm to 8 mm Visual Indication in Weld at LH Front Strut Tower |
| 615 | 521764 | 15 Oct 87 | • 4 mm Visual Indication in Weld at LH Front Strut Tower |
| | | | • 5 mm Crater Crack in Weld at RH Front Strut Tower |
| 619 | 521776 | 14 Oct 87 | • 5 mm Underbead Crack in Weld at RH Rear Strut Tower |
| | | | • 4 mm Crater Crack in Weld at RH Bulkhead to Sidewall |
| | | | • 5 mm Crater Crack in Weld at RH Rear Strut Tower |
| 627 | 521778 | 16 Oct 87 | • 5 mm Underbead Crack in Weld and 6 mm Straight Edge Crack at LH Rear Strut Tower |
| 626 | 521780 | 17 Jul 87 | • Crack From LH Front Cap Weld and into Side Plate |

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The problem of cracking in Light Armored Vehicle (LAV) strut caps made of high hardness armor was addressed. The current manufacturing process is reviewed, as well as the history and mode of cracking. A finite element method was employed to elucidate the stress field in the strut cap and in the surrounding ballistic hull. Finally, alternative fabrication procedures and designs are proposed and recommendations given to alleviate this problem.